

NATURAL ELF NOISE EVALUATION
FOR TSS EMISSIONS DETECTION ON THE EARTH'S SURFACE
The Electric Field Component Approach

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Abstract: The preliminary estimate of the local noise structure in the proximity of a receiver is essential to establishing the detectability of a given signal in presence of such noise. This memo outlines the possibility of detecting the Electric Field Component of the background noise by means of electric dipoles horizontally placed on the sea bed in shallow waters, in order to find its spectral and statistical characteristics for the definition of the optimal receiving system.

1. Introduction

The detection on the Earth's surface of possible electromagnetic emissions in the ELF range radiated by the TSS is, in principal, a communication problem. A sufficient amount of energy available at the receiver is, of course, necessary for the operation of any communication system in the presence of background noise. Energy transmission factors are, however, insufficient to evaluate or optimize a receiving system as soon as it includes relatively advanced signal processing techniques. In order to estimate the detectability of a hypothetical signal by a receiver, several pieces of information are needed:

1. Signal characteristics (the transmitter).
2. Boundaries and propagation conditions (the medium).
3. Background noise information in terms of spectral and time/space statistical structure in proximity of the receiver.
4. Receiver characteristics (the receiver).

2. The scenario of the experiment is shown in Figure 1. The space where the propagation of the emission takes place is represented in the main, by a number of layers. In case of detection on the bottom of the sea, the above-mentioned layers are:

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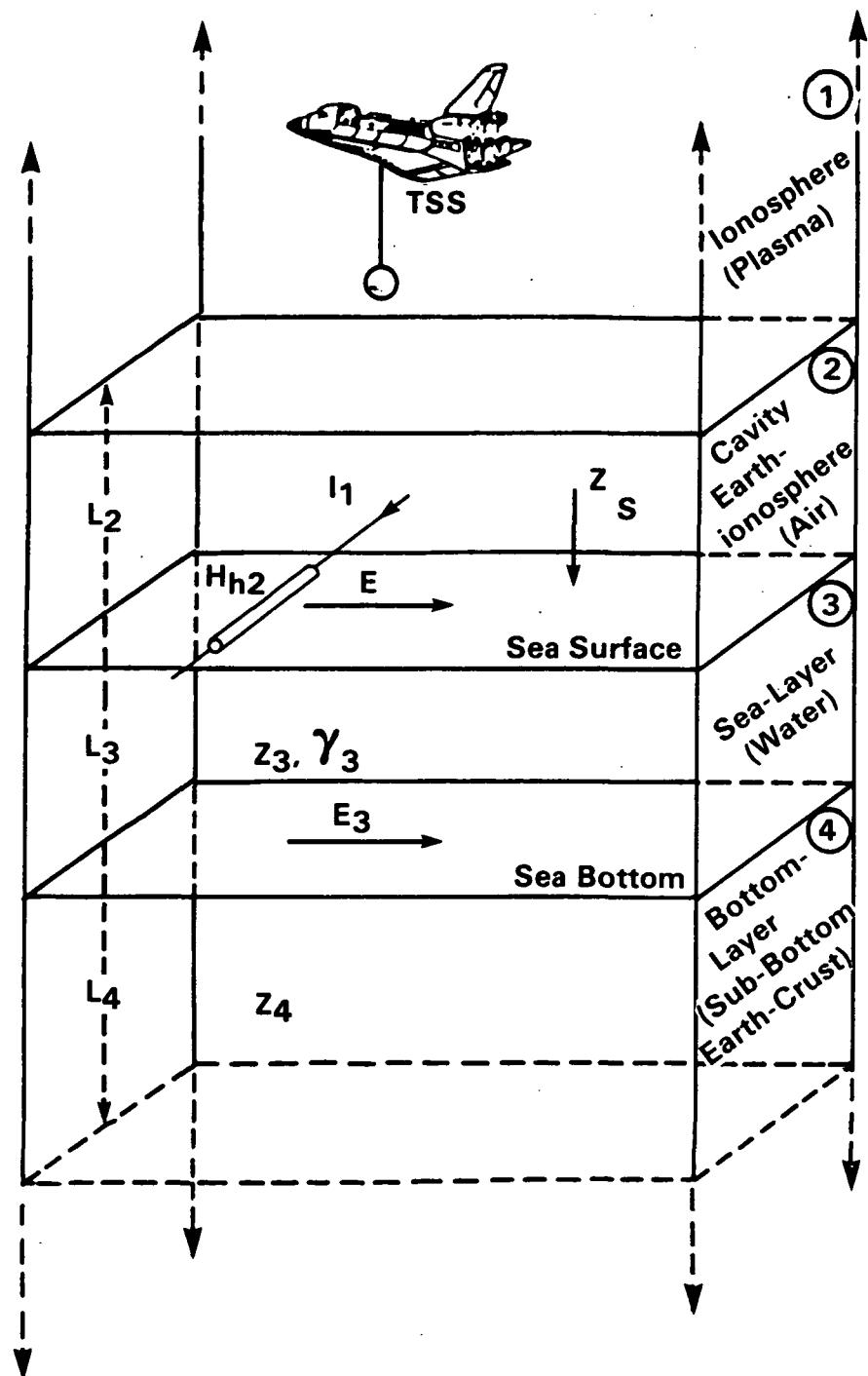


Figure 1. Propagation Scenario Structure

- I. The ionosphere
- II. The Earth surface/ionosphere cavity
- III. The sea layer
- IV. The sub-bottom Earth crust layer

The zone which we are interested in for the present investigation is that related to the II, III, and IV layers of Figure 1.

3. The natural background noise propagates as plane waves from the sea surface to the bottom, where the receiving electric dipole is placed. The water layer is equivalent to a transmission line of length L_3 (Figures 2a and 2b).

The current I in the transmission line (Figure 2b) corresponds to the horizontal component of the magnetic field strength in air, H_{h2} , which is practically independent from the characteristics of the water and the bottom. The load of the transmission line is represented by the bottom impedance Z_4 . Assuming the bottom of infinite depth ($L_4 = \infty$), the difference of potential in the water, E_3 is given by:

$$E'_3 = H_{h2} \times z_3 \quad (\text{for } L_3 = \infty) \quad (1)$$

$$E''_3 = E'_3 \times \frac{z_2}{z_3} \quad (\text{for } L_3 = \text{finite}) \quad (1')$$

For a water depth $L_{3f} = L_3$ finite

$$E_3 = H_{h2} \times z_2 \quad (2)$$

which gives the ratio:

$$\frac{E''_3}{E'_3} = \frac{z_2}{z_3} \quad (3)$$

and consequently:

$$E''_3 = E'_3 \times \frac{z_2}{z_3} \quad (4)$$

$$E''_3 = E'_3 G \quad (G = z_2 / z_3) \quad (5)$$

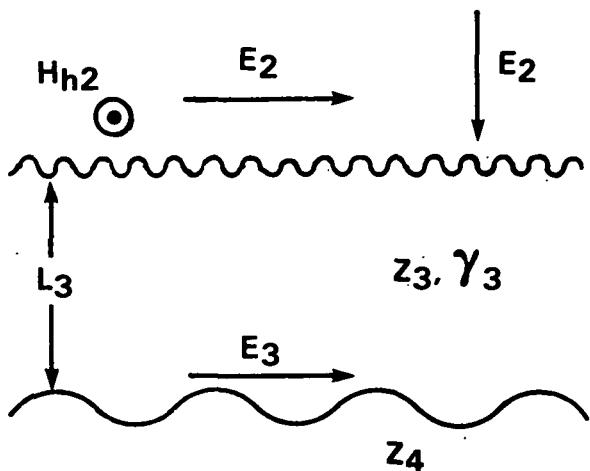


Figure 2a.

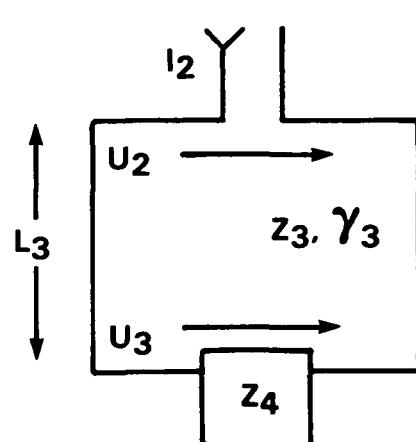


Figure 2b.

$$\gamma_3 = \sqrt{j\sigma_3 \mu_0 \omega}$$

propagation constant in water

$$Z_3 = \frac{j\mu_0 \omega}{\gamma_3}$$

water impedance

$$\begin{aligned} \gamma_3 &= 4 \text{ mhos/m} \\ \mu_0 &= 4\pi \times 10^{-7} \text{ H/m} \\ u &= 2\pi f \end{aligned}$$

water conductivity

Figure 2. Various Quantities Characterizing Propagation in Water

From the theory of transmission lines, we obtain:

$$Z_2 = Z_3 \frac{\tanh \gamma_3 L_3 + \frac{Z_4}{Z_3}}{1 + \frac{Z_4}{Z_3} \tanh \gamma_3 L_3} \quad (6)$$

This expression is valid for $\sigma \gg \omega \epsilon$ neglecting the displacement currents.

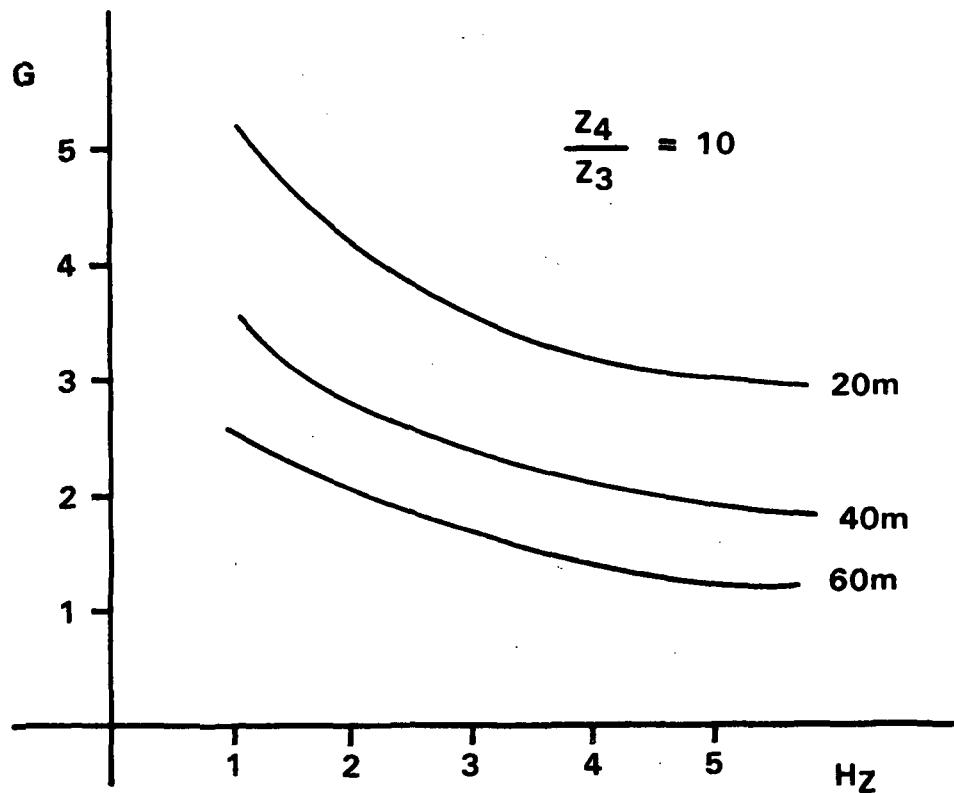
As an example, for $L_3 = 20$ m and assuming $L_4 = \infty$ we have:

$$Z_4 = Z_3 (\sigma_3 / \sigma_4)^{1/2} \quad \begin{aligned} \sigma_3 &= \text{water conductivity} \\ \sigma_4 &= \text{bottom conductivity} \end{aligned} \quad (7)$$

The observed background noise is increased by the factor $G = Z_2 / Z_3$. For a typical value of $\frac{Z_4}{Z_3} = 10$, the factor G is given as a function of frequency for three bottom depths of 20, 40, and 60 m (Figure 3).

4. The electric dipole behavior in sea water is discussed in Reference 1.

The difference in potential between the electrodes of a dipole is:



$$G = \frac{Z_2}{Z_3}$$

For $Z_4 = Z_3$

$$\sqrt{\frac{\sigma_3}{\sigma_4}}$$

Figure 3. The Impedance Ratio G as a Function of Frequency From the Theory of Transmission Lines

$$U_{AB} = EL$$

L = dipole length

E = electric field component

The impedance of the dipole is:

$$Z_D = R_D \frac{k}{S}$$

R_D = Resistive part of Z_D
k = form factor of the electrode
S = surface of the electrode

for an electrode similar to a prolate ellipsoid, we have:

$$Z_D = R_W + 2R_z \text{ (prolate ellipsoid)}$$

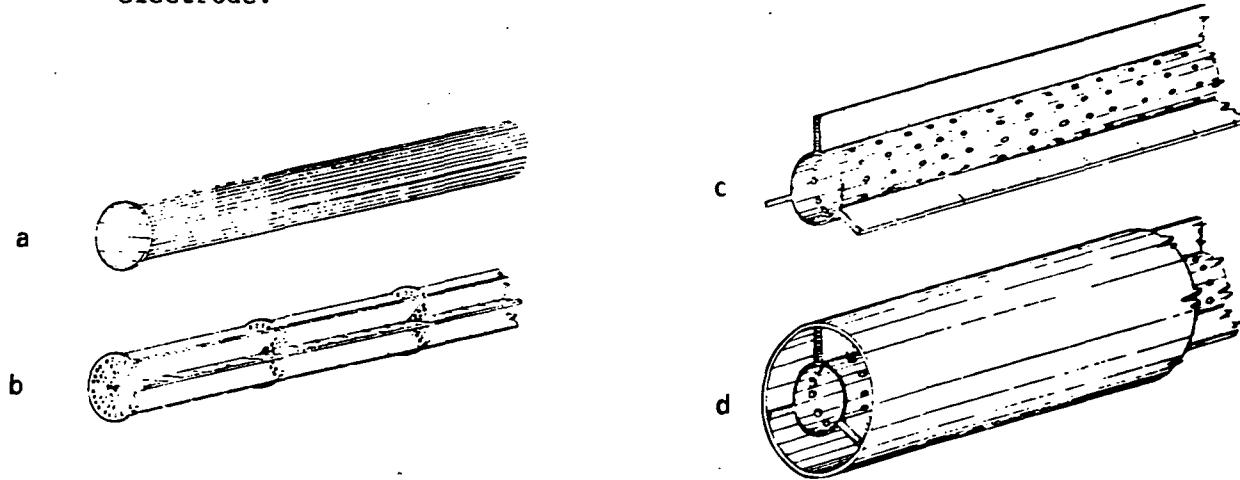
$$Z_D = R_W + 2 \frac{\operatorname{arctanh} \sqrt{1-(b/a)^2}}{2\pi\sigma a \sqrt{1-(b/a)^2}}$$

and for a = 50*

$$Z_D = R_W + 2 \frac{(0.08(\Omega/m^2))}{\sqrt{S}}$$

*"a" and "b" = axis of prolate ellipsoid

Figure 4 shows the phases of construction of a low intrinsic noise electrode.



a. Fifty-four 7.5 m, 6 mm dia. zinc rods attached to 10 cm diam. zinc plate.
b. Pipe is cut to separate rods and reduce water flow.
c. Pipe surrounded by 6 mm
d. Second surround - 1/2 in.

Figure 4. Construction of a Low Noise Electrode

Figure 5 shows an experimental dipole assembly 7 m long. Two such dipoles were horizontally placed on the sea bottom parallel to each other and separated by 1 km. Performances of such systems can be strongly improved with new design and construction.

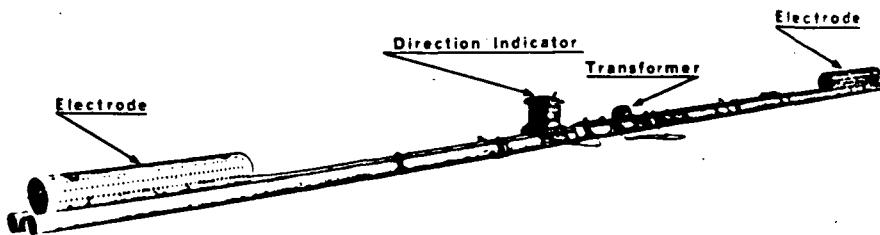


Figure 5. Experimental Dipole Assembly

Figure 6 shows the power spectra of the two signals simultaneously recorded. Here we observe the space correlation effect which reduces the far off noise (Shuman modes).

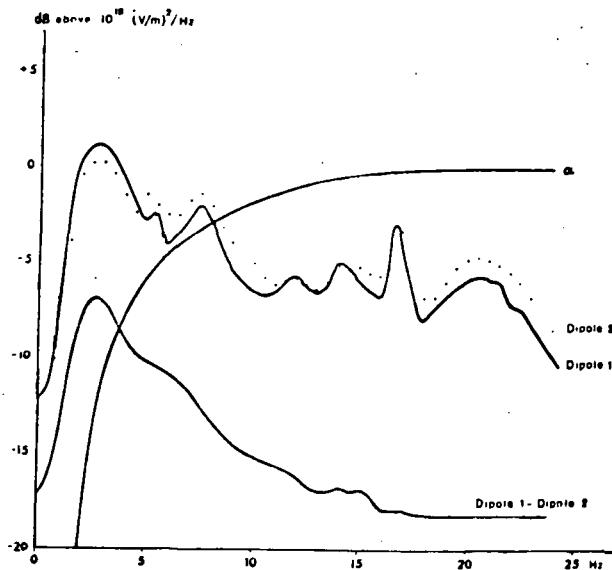


Figure 6. Power Spectra of Natural Background Noise Measured by Two Dipoles 1 km Apart and of the Difference Signal.
(The power spectra are multiplied by the factor a)

Figure 7 shows theoretical and measured ELF background noise (J. Galejs and Balzer & Wagner). The first three Shuman modes are evident.

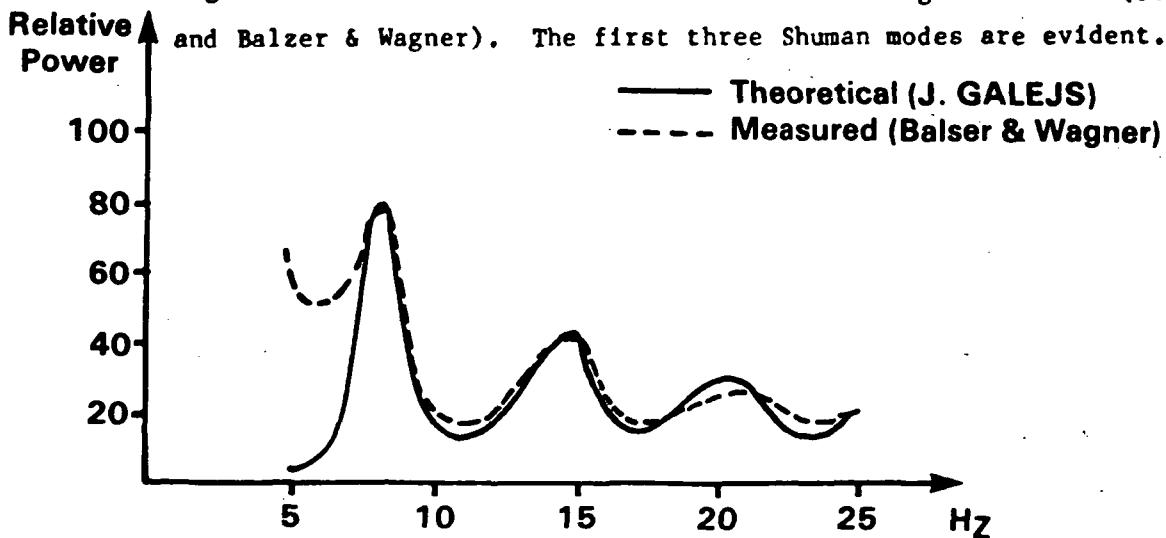


Figure 7.

6. Concluding Considerations

Simultaneous recording of horizontal electric E_n and horizontal magnetic H_n field components should give a highly reliable validation of the theoretical estimate of the electromagnetic field distribution on the Earth's surface.

a. The Target

Measurements of VLF/ELF emissions radiated by the TSS at Earth's surface.

o Evaluation of received signal in comparison with theoretical estimate of MIT/SAO program, in terms of:

- Radiated energy
- Noise level for a possible transmission channel.

oo For the derivation of the optimal receiver, preliminary natural and man-made background noise measurements will be performed at the selected site.

b. The Site

The choice of the most favorable site depends on the results of the MIT/SAO program. Anyway, a possible selection of sites is as follows:

- Tynerian Sea (Tino) in case of guided propagation
- Central Med. (Lampedusa) - compromise conditions
- Canary Islands (Spain) - closest point of approach - hot spot

Logistic problems will be solved by the Italian Navy - CMR - and tentatively, by the Spanish Institute Astrofíneo de Canarias (Tenerife).

c. The Instrumentation

Special coil sensors are supplied by NUSC (M. E. Soderberg) - presently in calibration. Cesium magnetometers (total field) will also be used.

Recording equipment (multichannel FM tape recorder battery operated) and general instrumentation with additional electronics will be supplied by the University of Genoa (DIBE), the Italian Navy, CNR, and Saclantceu (la Spezia).

d. Received Data and Analysis

From the preliminary investigation on local noise, which is expected to be non Gaussian, and its characterization on Type A or B (Middleton), the structure of optimal receiver will be derived, i.e., LOTR (Locally Optimum Threshold Receiver). This process and subsequent spectral analysis and signal processing will be done at the University of Genoa (DIBE).

To establish a common methodology for obtaining comparable results, we are in contact with other groups interested in detecting TSS emissions:

- Rice University, Professor Gordon
- Stanford University, Prof. Hellinell

Analytical cooperation will be given by various Italian groups:

- Univ. Florence - Prof. Buscaglioni
Prof. Pellegrini
 - Marconi Italiana - Prof. Martini
 - CNR-IAN - Prof. Volta.

7. References

1. G. Tacconi, "Fundamentals of ELF Communications and Detection," AGARD Lecture Series No. 88, Oslo-Denhelder-Rome, Oct. 1977.
 2. G. Tacconi, "On the Evaluation of Man Made Electromagnetic Noise Interfering with Communications in the ELF Range," AGARD EPP Meeting, Paris, Oct. 1974.